

N94-23899

A CROSS-DISCIPLINARY RESPONSE TO IMPROVE TEST ACTIVITIES

The Corporate Memory Capitalization in Ariane4 Test Domain

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ABSTRACT

The AIT/AIV of the Ariane4 Vehicle Equipment Bay has been held at Matra Marconi Space (MMS) site of Toulouse for several years. For this activity, incident interpretation necessitates a great deal of different knowledge. When complex faults occur, particularly those appearing during overall control tests, experts of various domains (EGSE, software, on-board equipment) have to join for investigation sessions. Thus, an assistance tool for the identification of faulty equipment will improve the efficiency of diagnosis and the overall productivity of test activities.

As a solution, the Aramiihs⁽¹⁾ laboratory proposed considering the opportunity of a knowledge based system intended to assist the tester in diagnosis. This knowledge based system is, in fact, a short-term achievement of a long-term goal which is the capitalization of corporate memory in the Ariane4 test domain. Aramiihs is a research unit where engineers from MMS and researchers from the Irit⁽²⁾-CNRS⁽³⁾ cooperate on problems concerning new types of ma-system interaction.

KEYWORDS

Corporate Memory, Ariane4 Test, Diagnosis, Knowledge Acquisition, Expert System, Case Based Reasoning

I. INTRODUCTION

Information technology can help companies achieve higher productivity and better reliability in decision making, communication and activities

organization. With the large range of technical possibilities at hand in realizing applications, people become more and more aware of the importance of matching the right technique with the right need and of evaluating the impact of this solution upon organizations.

So far, we are taking part in the emerging awareness of two fundamental aspects when new information processing systems are to be defined. These features have been recently taken into account in information technology and data processing system design and development.

The first aspect stresses the evaluation of the aim impact (need analysis and organization study) and the choice of an appropriate combination of techniques to achieve this aim. The second point focuses on the time required for the aim to be achieved. If realizing the application is to take a long time, a way to turn such a long-term project (which can make end users discouraged and unmotivated) into efficient short-term ones is to propose an incremental design and development. The objective then becomes the gradual realization of an application

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that gives benefits to its end users at each step of its achievement and thus will maintain the interest and participation of those end users.

In this paper, we describe the development of a knowledge based system for diagnosis assistance. It is intended to be used in the context of Ariane4 Vehicle Equipment Bay (VEB) Assembly, Integration, Test and Validation (AIT/AIV) activities. This knowledge based system is, in fact, the first short-term achievement. The long-term goal is to capitalize technical memory in the Ariane4 test domain.

The long-term aim is to make knowledge well provided among people in a work environment and to have them participate in the enrichment and standardization of it. Thus, we have to plan the gradual development of the final system. The amount of the capitalized knowledge will be more important than the one needed by a 'standard' expert system. It is possible that the final system will consist of several systems (expert systems, intelligent data bases with multimedia accesses, intelligent tutoring systems, etc.). The final impact is of great importance since it both modifies the way people work (improves the productivity and skill of the staff) and the view they have of their work.

We will also detail in the paper our approach which is a cross-disciplinary one since it includes software techniques, Artificial Intelligence, and human factors evaluation. Such an approach is possible, thanks to the context provided by the ARAMIIHS laboratory, where engineers and researchers cooperate on problems raised by the development of complex man/machine interfaces.

OPERATIONAL NEEDS AND CONTEXT

2.1 The Ariane4 VEB

The AIT/AIV activities of the Ariane4 launcher VEB have been performed at the Matra Marconi Space (MMS) site of Toulouse for more than 10 years, and will continue for 10 more years before being totally replaced by the Ariane5 launcher.

The Ariane4 VEB is mechanically interdependent with the third stage of the launcher during the flight. It ensures the interface between the structure of the launcher and the satellite contained in the fuse cap.

The functionalities of the VEB allow it to:

- guide and control the launcher during the flight,
- send orders to the three stages of the launcher for the trigger or stop of the propellant systems, the separation of the stages, the release of the fuse cap and the satellite, and the change of data format of the telemetry,
- verify the state of the satellite and control its release,
- satisfy security constraints by localizing the launcher and, if necessary, by destroying it,
- allow, during the preparation of the launcher and its flight, the transmission of telemetries to control centers for the verification of the correct operation before launch and during flight,
- and process, before launch, the telecommands necessary to control and bring into operation different elements of the launcher. In figure 1, we have the different functionalities of the VEB.

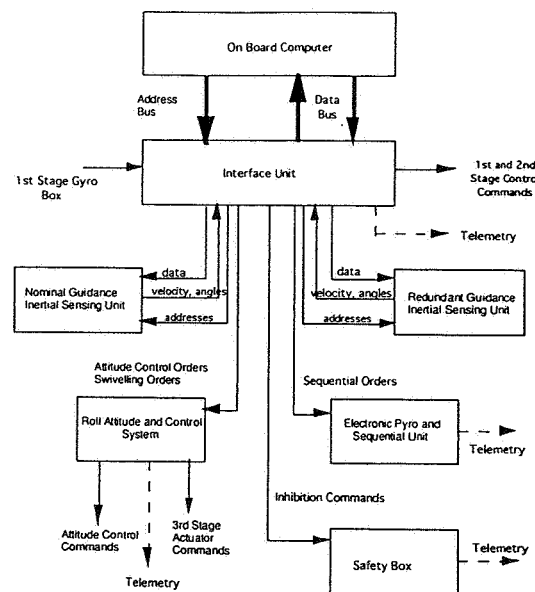


Figure 1 VEB FUNCTIONAL SYNOPSIS

2.2 The AIT/AIV Activities

As it was said previously, the MMS site of Toulouse is in charge of the AIT/AIV activities of the VEB. Those activities include the last tests on the VEB before it is sent to Kourou (the launch site).

2.2.1 Tester Behavior Confronted With an Incident

During the test phase, when an incident occurs, integration responsables begin the diagnosis by an analysis phase. This analysis phase requires understanding the context of anomalies through the appearance of symptoms, and having the appropriate knowledge, experience and information related to the incident. From this analysis phase, a hypothesis will be made. Then, there will be decisions on complementary tests to run in order to validate the hypothesis and to localize better the cause of the incident.

Thus, those activities necessitate from testers a good amount of knowledge in test environment which is composed of:

- the VEB under test
- the test bench
- the software of the on-board and ground computers
- the specification of tests

The knowledge lies both in documents and in the expert testers' experience. The documents needed during a diagnosis are numerous: ground software specifications, test specifications, test bench and VEB documents, electrical plans, etc. Testers' experience necessary for the investigation must cover all the equipment involved in the test. Part of the equipment is shown in figure 1.

Hence, when complex faults occur, particularly those appearing during overall control tests, experts of various domains (EGSE, software, on-board equipment) have to conduct investigation sessions and search for the faulty equipment. These sessions, though necessary, require important time expense from different specialists. Moreover, testers sometimes spend a large amount of

time dealing with problems that could be easily solved by experts. Thus, an assistance tool for the identification of faulty equipment will improve the efficiency of diagnosis and the overall productivity of test activities.

2.2.2 The Existing Management of Incidents

All the incidents are written down on nonconformance reports. These reports can be, if necessary, consulted to find out whether the present incident already occurred in the past. They are attached to documents describing the diagnosis approach that was taken in the search of the cause of incidents. They can help testers to elaborate an appropriate diagnosis approach for a current incident.

2.3 THE NEEDS

2.3.1. An assistance for the Evaluation of the Context

When confronted with an incident, integration responsables have to take into account the global context in which the incident appears. This is a critical phase since from this context evaluation, testers will take actions such as complementary tests to determine the cause of anomalies. A good evaluation of context will allow carrying out appropriate actions, the impact of which will not disrupt the diagnosis process and the incident context.

2.3.2 A Reduction in the Time Required for Diagnosis

When an anomaly occurs during the test phase, the rapidity of its resolution will improve the global productivity of test activities.

This is particularly true when the VEB is under tests with special conditions such as vibrations and thermal constraints. Indeed, in this context, the faster the correct diagnosis, the better it is, since that prevents exposing the VEB too long under environmental conditions that are far harder than real ones.

2.3.3 A Search for Appropriate Information to Make a Reliable Diagnosis

The diagnosis must be reliable. The performance of a reliable diagnosis depends on the identification of correct information. Hence, it is necessary, when an anomaly appears, to look for useful complementary information. That information is linked to the context of the anomaly appearance.

Another consideration is that several types of anomalies can have similar symptoms on the test results. Hence, complementary tests will permit obtaining more information. The diagnosis approach must follow a strategy which ensures an optimization of actions to be performed and a maximum of reliability and safety.

2.3.4 Adaptation of Old Incident Solutions to Present Anomalies

The rapidity, the efficiency, and the analysis approach are often achieved owing to the experience of testers. This experience relies on adapting diagnosis process from old cases to present problems. Thus, old cases can be of great help in understanding the present context and elaboration of the diagnosis approach.

3 THE RESPONSE

As a solution, we consider the opportunity of a knowledge based system intended to assist testers in diagnosis. Given an incident, the system will assist users in making good hypotheses and in having an appropriate process to run complementary test actions to validate the hypothesis.

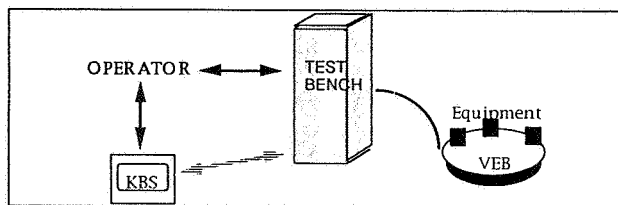


Figure 2: The integration of the expert system in the test environment

To manage the acceptability and the introduction of AI techniques and culture in this operational environment, we benefit from an expert completely involved in the development of the expert system itself. This aspect will also serve

our long term goal, which will be detailed in the next paragraphs.

The main originality of our approach is to consider the solution and the knowledge based system as a cooperative tool that should help the operator. This point of view differs from the usual ways of considering AI applications, which often neglect the user.

This focus on the user induces implicit yet significant changes in the status of the system to be developed:

- building an expert system results in putting expertise at the user's disposal through an artifact,
- the design of the system not only focuses on the expertise itself, but also on the way the expertise is communicated and made available to nonexperts,
- the knowledge based system (KBS) becomes much more dependent on its use context and on the technical environment it will be integrated in.

A KBS will not meet these requirements unless it behaves like an intelligent team-mate, a cooperative tool that contributes to the improvement of the user's task achievement with its own competencies.

Considering a KBS from this perspective has several consequences on the way it must be designed. We intend to take such constraints into account in the life cycle we follow to develop AI applications. Our methodology combines results from human factors, knowledge engineering and modelling to ensure the system acceptability by the end users.

--The work organization in which the system will be settled is to be taken into account as soon and as closely as possible. This refers to the work organization, the people concerned with the project, existing and future

tools, etc. The purpose is to manage a good integration of the system within this context. The previous paragraphs describe the AIT/AIV context and work activities.

--Building a cooperative system requires a strong reference to the user's abilities and know-how in performing the test, both with and without the help of a system. The user's task analysis provides information about the user's needs and the expected functionalities and roles of the target system. It helps specify the kinds of cooperation expected. AIT/AIV operators expect the diagnosis expert system to save time in localizing causes of defaults and to explain its diagnosis process.

--The acquisition of the knowledge required by such a system should not be restricted to the early stages of the system life-cycle, but it should be continued to enrich the system as long as it remains in use. We promote a modelling approach, where knowledge acquisition consists of building an expertise model independent of the symbolic representation in the knowledge base. This model serves as a medium of communication between the expert, the knowledge engineer and, later, the maintenance engineer. It provides a frame that guides the acquisition and modelling of new knowledge. Such a model is to be translated in order to obtain the target system. The representation primitives should help design a cooperative system, that is to say, they should make it possible to explicate how the solving process can be adapted, according to strategies or context dependent constraints.

- Validation of a KBS results from much more than the knowledge base qualification. The life cycle includes a step-by-step validation by users and experts. We consider the system as valid only after three kinds of properties have been checked: (i) it performs correctly the task it is intended to, (ii) the user understands what the system does (there is a "cognitive compatibility" between the users and the system solving processes), and (iii) the system fits in its use environment (it is integrated with existing systems, practices and tools).

In order to ensure the system usability, an experiment has been carried out with expert and non-expert operators. The language they use and the level of abstraction at which they solve a problem have been compared. The differences stressed will be taken into account in order to adapt the system interface and the kind of explanations it provides.

3.1 THE SHORT TERM GOAL

The knowledge contained in the expert system will allow dealing with the more usual problems encountered during overall control tests. Diagnosis during this particular type of test is difficult since all the equipment of the VEB is simultaneously functioning. Thus, when an anomaly appears, a global knowledge of the VEB is necessary to decide on the appropriate approach. In agreement with the expert, we decided that the system will mainly consider the cause of anomalies as unique.

At the present time, we are developing the prototype. It is planned to be delivered to testers in March, 1993. Having the system at hand will allow testers to suggest some modification or add-ons about the functionalities of the system. Presently there are suggestions from testers to implement explanation modules in the system. This will enable the system to justify and explain the deduction of its hypothesis and its diagnosis process.

In the same way, the knowledge stored in the system will be available for testers to use and to make suggestions for its enrichment.

3.2 The Long-Term Objective

Our final objective is to make VEB test knowledge available to all testers. The knowledge stored in the expert system will then be enriched by different experts of different equipment of the VEB. In effect, initially the expertise stored in our system only concerns that of an expert in VEB tests. Then, as the system is used and AI techniques and culture is better understood by end users, we will better identify which

kind of knowledge from experts of specific VEB equipment can be added. Moreover, these experts will feel much more involved in the system design at that time.

Figure 3 illustrates our approach.

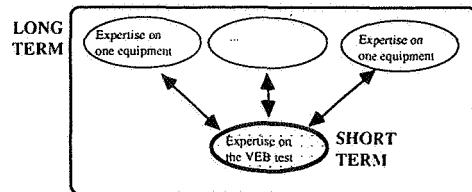


Figure 3: The expertise domain covered by the system in short term and long term perspectives

Presently, experts of different domains in integration plan to evaluate the expertise of the system at the end of this year. Thus, it will be the first session where there will be a discussion on the quality of the system knowledge and also proposals to enrich it.

Thus, by means of the system, we plan to make the knowledge as living as possible in the growth both of quality and quantity. And as the knowledge grows, the functionality of the system will grow as well. The results may be developments of different applications. Indeed, as we know better the context of test integration environment, we will have a deeper insight as to what can be done to still improve test activities in quality and productivity.

To conclude, we aim at capitalizing the corporate memory of the test environment. This task implies gradual achievements which result in the development of advanced information processing systems such as expert systems. The making of these systems in turn will encourage people in test environments to improve and enrich the corporate knowledge in the Ariane4 test context.

4 THE APPROACH

To achieve the short-term goal we are carrying out the knowledge acquisition, the definition and realization of the system architecture and the definition of the man/machine cooperative model.

The first two phases are more complex

to achieve than by simply operating in the context of realizing a simple knowledge based system. Indeed, we have to lay clues for the long term goal. The last phase is useful for us to take into account the different constraints that are applied in test environments and, by this, to study the behavior of testers in various situations and contexts. This will help us to design well-fitted systems to end-users needs.

4.1 Knowledge Acquisition

As mentioned earlier, we stress the interest of knowledge modelling for knowledge acquisition. The model facilitates the understanding of the knowledge stored in the system and of its behavior when performing a task. It makes explicit the way the system will solve a problem, adapt its behavior according to the current goal and context, etc. The conceptual model can be considered a detailed specification of the knowledge base, independently of how it will be implemented.

Such a model is used, of course, to acquire knowledge from the expert and to build up the system, but also to maintain it, to generate better explanations, etc. Even though making it explicit takes time, it turns the famous "knowledge acquisition bottle-neck" into a succession of modelling activities much more guided and efficient than rapid prototyping.

In this project, knowledge acquisition is carried out following the MACAO methodology and using the associated tool. This method promotes a bottom-up modelling process from the analysis of cases solved by the expert. Model-based knowledge acquisition can be decomposed in four major stages:

- data-driven knowledge acquisition where information (rough data) is drawn from the various knowledge sources (expert's activity, documents, etc.) without any predefined idea about the expertise,
- abstraction of a schema of the conceptual model: the tasks performed by the expert are characterized as well as the methods he uses and his strategies; also his

representation of the domain entities is associated to a kind of model structure,

- building of the full conceptual model: the schema of the model is filled with all the required application knowledge until the model is complete; the schema may be consequently refined,

- implementation of the conceptual model as the target system knowledge base.

Figure 4.1. shows the different stages in knowledge acquisition and modelling.

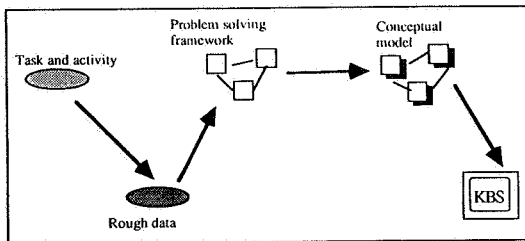


Figure 4.1.: Stages in knowledge acquisition and modelling

With MACAO, several techniques are suggested in order to carry out each stage. A software helps build up the model: it proposes knowledge browsers and editors, structures for the model formalization. The conceptual model consists of two components: a domain model which gathers static knowledge about the expertise domain (concepts and their relations); a problem solving model that represents the task decomposition describing how a problem can be solved. Each model is represented with a specific language: semantic networks for the domain model, a graph of schemas for the problem solving model. Both are shown through graphs editors.

The techniques promoted by MACAO are derived from human factors psychology or ergonomics, as well as knowledge acquisition. For instance, for data-driven knowledge acquisition, one of the techniques proposed is problem simulations, followed by focused interviews bearing on explanation of the simulations. Repertory grids are used to identify classes of problems. The problems solved by the expert

form a set of cases that are compared in order to abstract the characteristics of the expertise and the schema of the conceptual model.

The graph in figure 4.2. represents the schema of the conceptual model obtained with our application. The application is solved with a method close to systematic diagnosis, and exploits a functional model of the V.E.B.

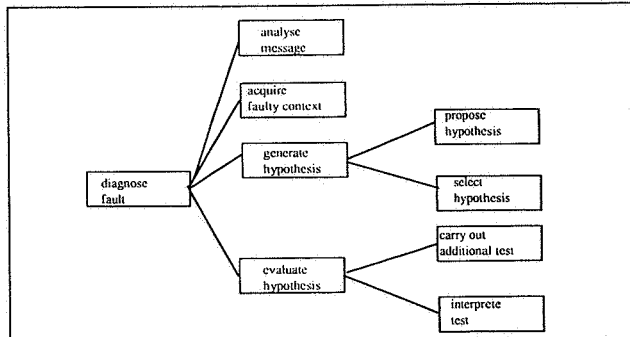


Figure 4.2. : The first stages in the diagnosis process modelled in the problem solving framework

The use of MACAO on this application facilitates the two stages scheduled in the project because the model can be increased step by step. Moreover, it helps understand better the expertise when the system is extended.

The schema of the conceptual model plays the role of a frame that guides implementation choices as well. Depending on the expert's availability, the system can be developed with more or less expertise. The least amount of knowledge required is the schema of the conceptual model. It can be used to decide whether the system can be built with a case-based or a model-based reasoning approach. It provides information on the kind of domain model used for model-based reasoning for instance.

4.2 THE SYSTEM ARCHITECTURE

We define the architecture of the diagnosis expert system as a hybrid one: it relies on rule based, case based and model based reasoning (see Figure no. 4.3).

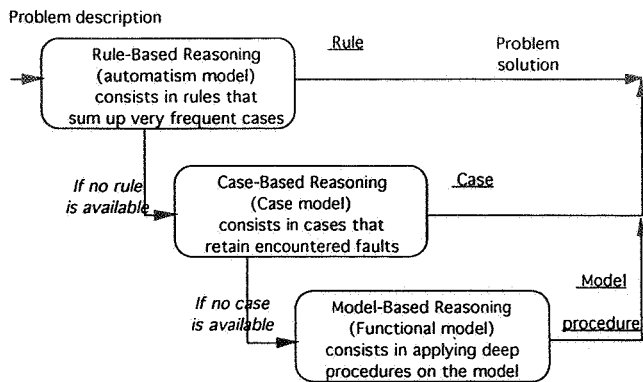


Figure 4.3 The distribution of the three model competence

Our goal is to combine AI techniques that can propose an efficient model of an expert's problem solving process. We assume suitable to combine Rule Based Reasoning, Model Based Reasoning (MBR) and Case Based Reasoning (CBR) techniques. Given an incident, the system will first rely on rules. If it doesn't succeed, CBR will be triggered to look for similar old cases. This can shortcut the model based diagnosis. Otherwise, the MBR must be triggered on the functional and structural model of the VEB. It can then assist the user or resolve the problem if its knowledge is strong enough.

4.2.1 CBR as a Component of a Hybrid Architecture

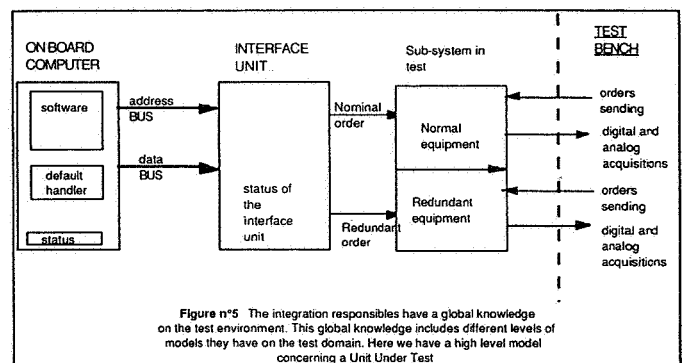
We decided to adopt case based reasoning techniques for two reasons: the expert refers to previous cases to solve new problems and many occurring incidents have already been encountered. Thus, when an incident occurs, the system will search for similar old cases to adapt the diagnosis approach to the present case. Explanation facilities concerning system reasoning will partly rely on the Case Based Reasoning architecture.

4.2.2. CBR and the Domain Model

The integration responsible has an overall view of his test environment. Thus he has a general knowledge of the system he has to test and of the test bench he uses. When an anomaly occurs, he has to find out the cause of this anomaly and to detect from which equipment it comes. In general, his diagnosis process ends when one equipment of the system in test is identified as guilty. Indeed,

it is beyond his knowledge to thoroughly detect which part of the equipment is faulty. But by experience, he can have partial knowledge on the inside of the equipment.

Thus, to ensure the modification and enrichment of our anomaly cases, we have to realize a global model of all the systems involved in the test (sub-systems in test, interface unit, test bench...) and their connections with each other. This modelling corresponds to the view the expert has on the test environment and is, in fact, constituted with different levels of models. The following drawing (figure 5) illustrates a high level model concerning a Unit Under Test. (Lower level models correspond to more details for each equipment represented in the high level model).



In addition to the description of the anomaly, we have to define all the concepts associated to the contexts in which the anomalies occur, such as symptoms, anomaly causes, and test context. Examples are: message-coming-from-the-test-bench, single-message, and sub-system-A-in-fault.

4.2.3 Case Organization in Ariane4

In Ariane4, we organize cases of anomalies in a two-level hierarchy:

At the higher level, we have a set of super cases that gather subtypes of cases. A super case is characterized by common features of all the cases that belong to it. Of course, cases under super cases can have additional features just like subclasses and classes in object oriented programming paradigms. At the lower level, we have cases with their own

specific features.

Given an incident, the system will search if there exists a super case with features that correspond with that of the incident. If this super case exists, then the system will go through the organization under this super case to localize potential similar old cases. Globally we can say that the super cases regroup information related to external symptoms that occur and the case organization under the super cases corresponds to the diagnosis approach.

4.2.4 The System Architecture and the Long Term Objective

In defining the architecture, we are particularly focusing on the possibility for the system to have its knowledge enriched and maintainable. Each time we have new knowledge to integrate in the system, we have to study its significance and impact. In effect, we can integrate this knowledge as new cases of anomalies (by using the Case Based Reasoning architecture), as new items of modelization (by using the Model Based Reasoning architecture) and as new heuristics (by translating them first at the level of the expert system conceptual model and then by coding them in the rule based architecture).

4.3 COOPERATIVE MODEL

To adapt better the system to users' cognitive and physical skills, the man-system cooperation has to be precisely defined. The cooperative process, in our approach, is organized in a three layer model:

- the nucleus is a theoretical cooperative model,
- the theoretical model is shaped by operational environment constraints,
- the users behavioral model defines the cognitive compatibility between system and users.

As a project parallel to that of corporate memory, we are building a cooperative model responding to the three above criteria. A system with such a cooperative model is capable of adapting its dialogue with the

levels of users. Thus, for instance, the information (results, explanation, and reasoning) will be presented according to the testers' level of competence.

This cooperative, for its advanced concepts, will not be implemented in the knowledge based system. But realizing it allows us to have more insight in the definition of the interface and functionalities of our expert system.

Indeed, the cooperative model allows us to take better into account constraints of the work environment, characteristics of the work organization and human factor aspects in the context of Ariane4 VEB AIT/AIV activities.

5. CONCLUSION

Introducing the expert system in the context of Ariane4 VEB AIT/AIV activities will change the work organization. Indeed, when confronted with an incident, instead of only referring to documents and to human experts, testers can use the system as a source of knowledge and consider it as a tool of their own. Besides, they know that they can improve the performance of this tool by modifying and enriching its knowledge. Hence, in such a context, the work productivity is ensured as well as the technical level of the staff is kept high owing to the introduction of such a system.

The approach we adopt in the context of Ariane4 to capitalize the corporate memory can be adapted in the context of satellite integration or in other work environment. At each environment, our approach will allow us to identify and capitalize the know-how and the experience and then to translate them in terms of advanced information systems.

With the rise of information technology, one can feel overwhelmed in finding solutions to a problem encountered in his work environment. The approach we propose allow to master the solution by having a global understanding of the problem the parameters of which range from human factors to work domain. Hence, this enables us to have more insight as to choices in technical solutions.

Moreover, we enable a smooth introduction of advance systems in work organization to have more impact on the productivity and quality of work.

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